CHAPTER 2.0
SITE EXPLORATION FOR FOUNDATION DESIGN

To perform properly, a structure must interact favorably with the soil on which it rests. The modern foundation engineer, who often must build in areas which were considered too poor to build upon a few years past, must be well versed in the fundamentals of soil mechanics. This knowledge will be used in the design of structural foundations and earthworks to answer the following questions. Will settlements be excessive? Can the structure tolerate settlements? Will the proposed foundation type perform better than another type? Can the foundation soils safely support the imposed embankment or footing loads? Will the proposed cut or fill slopes have adequate stability?

The engineer should have adequate knowledge of the soil conditions at a site before attempting to answer these questions. By investing a few thousands of dollars into an adequate boring and testing program, costly failures or over conservative design may be prevented, resulting in design and construction savings of hundreds of thousands of dollars.

Foundation explorations should proceed through three phases

1. Initial studies and explorations to determine soil stratification and soil properties required for design.

2. Amplification, if necessary, of specific portions of the initial investigation to obtain more information both during the design phase and for preparation of contract documents.

3. Verification of anticipated foundation conditions during construction in order that changes may be made, if necessary, to either foundation design or construction procedures.

2.1 PREPARING FOR SITE EXPLORATION

The initial step in any highway project must include consideration of the soil or rock on which the highway embankment and structures are to be supported. The extent of the site investigation will depend on many factors, not the least of which will be the project scheduling, general subsurface conditions, and the nature of the loads to be supported. In any event, certain basic steps should be followed before a drill rig moves onto the project. The first step in the investigation is to collect and analyze all existing data.

Site exploration begins by identifying the major geologic processes which have affected the project site. Soils deposited by a particular geologic process assume characteristic topographic features, called landforms, which can be readily identified by the geotechnical engineer. A landform contains soils with generally similar engineering properties and typically extends irregularly over wide areas of a project alignment. Early identification of landforms is used to optimize the subsurface exploration program. The soil may be further described as a residual or transported soil. A residual soil has been formed at a location by the in-place decomposition of the parent material (rock). A transported soil was formed at one location and has been transported by exterior forces to a new location. Such landforms may be grouped as follows:

Landforms

1. TRANSPORTED SOILS

A. Aeolian (wind)

1. Sand dunes
2. Loess

B. Alluvial (water)

1. Flood plains
2. Terraces
3. Alluvial fans
4. Filled valleys
5. Coastal plains
6. Mountain outwash
7. Deltas

C. Glacial (ice)

1. Deposited by ice
   a. Moraines
   b. Till
   c. Drumlins
2. Deposited by water associated with ice
   a. Outwash
   b. Kames
   c. Eskers
   d. Lakebeds
   e. Terraces
   f. Deltas

2. RESIDUAL SOILS

A. Sedimentary

1. Flat-lying
   a. Sandstone
   b. Shale
   c. Limestone
2. Tilted
   a. Sandstone
   b. Shale
   c. Limestone
3. Interbedded

B. Igneous

1. Extrusive
   a. Basalt
   b. Volcanic cones
   c. Dikes
2. Intrusive
   a. Granite

C. Metamorphic

1. Quartzite
2. Gneiss
3. Schist
4. Serpentine
5. Slate

2.2 SOURCES OF EXISTING DATA

For a highway project, basic sources of geotechnical information should be reviewed to determine landform boundaries and to provide a basis for outlining the project subsurface exploration program. Those sources and functional uses are as follows:

Source	Functional Use
1. Topographic maps prepared by the United States Coast and Geodetic Survey (USCGS).	Current physical features shown; find landform boundaries and determine access for exploration equipment.
2. County agricultural soil map sand reports prepared by the United States Department of Agriculture (USDA).	Engineering significance and boundaries of landforms shown; appraisal of general subsurface conditions.
3. Air photos prepared by the United States	Detailed physical relief shown; flag major problems

	Geologic Survey (USGS) or others.	such as old landslides scars, buried meander channels, or scour; provides basis for field reconnaissance.
4.	Ground water resource or water supply bulletins (USGS or State agency).	Old well records or borings with general soils data shown; estimate general soils data shown; estimate required depth of explorations and pre-preliminary cost of foundations.
5.	Construction plans for nearby structures (Public agency).	Foundation type and old borings shown.
6.	Geology bulletins (USGS or State agency)	Type, depth and orientation of rock formations.

The review of available data should be done prior to the field reconnaissance to establish what to look for at the site. In the eighth Rankine lecture a noted speaker stated the following truism regarding site investigation: "If you do not know what you should be looking for in a site investigation, you are not likely to find much of value."

The type of information available from USDA county soil maps is particularly useful for landforms of transported soils.

2.3 PRELIMINARY GEOTECHNICAL DATA (AS INTERPRETED FROM USDA SOIL MAPS)

Common Landform Type	General Engineering Significance for Study
Sand Dune	Consider spread footings for small foundations not subject to vibratory loading. Heavy structural loads should be friction pile supported.
Loess	Consider spread footings for low to moderate loads. Heavy loads should be pile supported with bearing obtained below loess. Accurate ground water level determination important.
Flood Plain	Generally poor construction site with fine-grained soils and water problems. Potential scour area. Spread footing design below ground will probably require undercut, low foundation pressure and scour protection. Pile foundations probable. Additional shallow explorations required along footing length to determine buried meander channels. Historic high water levels should be used in design.
Terraces	Consider spread footings for low foundation loads.
Alluvial Fans	Consider spread footings for low to moderate loads except at lower elevation of alluvial fans where high water table possible.
Coastal Plain	Consider spread footings for moderate loads except for high water areas. Potential scour area. Soil set-up possible for friction piles.

Moraine	Advisable to use spread footings for all foundation loads. Piles should not be used due to very difficult driving and boulders. Core all rock to 10 feet in case boulders encountered.
Glacial Till	Advisable to use spread footings for all foundation loads. Piles should not be used due to difficult driving conditions and boulders. Core all rock encountered to depth of 10 feet as large boulders may be encountered. Long-term water observations necessary to determine static water level due to soil density.
Drumlin	Suitable for spread footing design with moderate to heavy loads. Piles seldom used due to dense coarse nature of subsoil.
Outwash	Spread footing normally used to support moderate to heavy foundation loads. Piles, if required, will be short. Use large diameter sample spoon to permit representative sample to be obtained as average particle size may jam 1 3/8 inch sample spoon. Standard penetration test may be erratically high due to large particle size.
Esker	Advisable to use spread footings for all loads as soil contains much gravel and is dense. Piles not recommended. Large diameter sample spoon recommended as above for outwash.
Kame	Suitable for spread footing to support moderate to heavy foundation loads. Piles, if required, will be short. However, deposit may be associated with deep steep-sided potholes containing unsuitable material. Shallow auger sample holes recommended along footing length.
Lakebed	Only suitable for spread footing to support low loads and then settlement may be expected. Pile foundation probable and often deep. Obtain undisturbed tube samples for laboratory testing. Consider drilling with "mud" rather than casing. Long-term water observations necessary to determine static water level due to impervious soil. Potential scour area.
Delta	The use of spread footings must be carefully studied as poor soils often underlie deltaic sands and gravels. The parent material is capable of sustaining high spread footing loads. Piles may be required to penetrate delta material and poor soil. Use casing of adequate size to obtain undisturbed samples of poor soil. Potential scour area.

The area concept of site investigation allows the foundation engineer to extend the results from a limited number of explorations in a particular landform to the entire deposit. This concept is a powerful tool in reducing subsurface exploration costs and in providing the planning engineer the following useful data in the location phase:

1. Highway design — Knowledge of the landforms and of the engineering properties of the soils enables the designer to determine the most economical location for highway alignment and grade, to evaluate design problems for each type of soil deposit, and to determine sources of granular borrow.

2. Highway construction — The type and extent of problem soils to be encountered during construction may be predetermined, and construction cost more accurately estimated.

2.4 FIELD RECONNAISSANCE

Application of the area concept requires the use of proper subsurface exploration equipment and techniques. In particular the use of wide area exploration techniques such as remote sensing of geographical techniques can provide economical insight of general subsurface conditions in the project area. An adequate site investigation can only be accomplished under the direction of a foundation engineer who knows the general limitations of the exploration equipment as well as the general demands of the project. A site inspection, preferably with the bridge engineer, is recommended to assess foundation conditions.

The field inspection for structure related foundation problems should include:

1. Inspect any nearby structures to determine their performance with the particular foundation type utilized. If settlement is suspected, and the original structure plans are available, arrange to have the structure surveyed using the original benchmark if possible.

2. For water crossings, inspect structure footings and the stream banks up and down stream for evidence of scour. Take careful note of the streambed material. Often large boulders exposed in the stream but not encountered in the borings, are an indication of unexpected subsurface obstructions to pile installation.

3. Record the location, type, and depth of any existing structures or abandoned foundations which may infringe on the new structure.

4. Relate site conditions to proposed boring operations. Record potential problems with utilities (overhead and underground), site access, private property, or obstructions.

Figure 2 – 1 is an example of a field reconnaissance form currently used to record data pertinent to the site. Upon completion of the site inspection, the geotechnical engineer should prepare a terrain reconnaissance report assessing the general suitability of the site. The report should:

1. Flag major potential problems, which may preclude construction.

2. Recommend beneficial shifts in location.

3. Present a general discussion of expected subsurface conditions.

4. Present cost estimate for out-of-the-ordinary foundation treatments.

5. Prepare an estimate of subsurface exploration quantities, costs, and time required for completion.

This information should be transmitted to the planning unit and the bridge engineer with copies to any other involved groups. Frequent communication between drill crew, foundation engineer, bridge designer and project engineer is necessary at all stages.

2.5 SUBSURFACE EXPLORATION PROGRAM

The procedures employed in any subsurface exploration program are dependent on a variety of factors which vary from site to site. However, the project design objectives and the expected site soil conditions have a major influence on the subsurface explorations. Highway projects necessarily involve both

BRIDGE FOUNDATION INVESTIGATION
FIELD RECONNAISSANCE REPORT
STATE HIGHWAY DEPARTMENT OF ________

Project No:__________ County:__________ Sta. No.: ___________
Reported by: ___________________________________

1. STAKING OF LINE
___ Well Staked
___ Poorly Staked (we can work)
___ Request Division to Restake

2. BENCH MARKS
In Place: Yes ___ No ___
Distance from Bridge - Ft. ___

3. PROPERTY OWNERS
Granted Permission: Yes ___ No ___
Remarks on Back ___

4. UTILITIES
Will Drillers Encounter Underground or Overhead Utilities? Yes ___ No ___
Maybe ___ At which Holes? ______
What Type? ___________________
Who to see for Definite Location ___
__________________ Feet _____

5. GEOLOGIC FORMATION

6. SURFACE SOILS
Sand ___ Clay ___ Sandy Clay ___
Muck ___ Silt ___ Other ___

7. General Site Description
Topography
Level ___ Rolling ___ Hillside ___
Valley ___ Swamp ___ Gullied ___
Groundcover
Cleared ___ Farmed ___ Buildings ___
Heavy Woods ___ Light Woods ___
Other ________________________
Remark on Back ________________

8. BRIDGE SITE
Replacing _____________________
Relocation ____________________
Check Appropriate Equipment
___ Truck Mounted Drill Rig
___ Track Mounted Drill Rig
___ Failing 1500
___ Truck Mounted Skid Rig
___ Skid Rig

Bridge Site – Cont'd
___ Rock Coring Rig
___ Wash Boring Equipment
___ Water Wagon
___ Pump
___ Hose ___ Feet
Cut Section – Feet ___
Fill Section – Feet ___
If Stream Crossing:
Will Pontoons be Necessary? ____
Can Pontoons be Placed in Water Easily?
____
Can Cable be Stretched Across Stream? ____
How Long? ____
Is Out board Motorboat Necessary? ____
Current: Swift ___ Moderate ___ Slow __
Describe Streambanks score.
If Present Bridge Nearby:
Type of Foundation ________________
Any Problem Evident in Old Bridge Including Scour ______(describe on back)
Is Water Nearby for Wet Drilling – Feet ___
Are Abandoned Foundation in Proposed Alignment? _______________________

9. GROUND WATER TABLE
Close to Surface – Feet _____
Nearby Wells – Depth – Feet ________
Intermediate Depth – Feet ___

10. ROCK
Boulders Over Area? Yes ___ No ___
Definite Outcrop? Yes ___ No ___
(show sketch on back) What kind? ___

11. SPECIAL EQUIPMENT NECESSARY

12. REMARKS ON ACCESS – Describe any problems on Access

13. DEBRIS AND SANITARY DUMPS
Stations ______________________
Remarks _____________________

Reference: 1978 AASHTO Foundation Investigation Manual

Figure 2 – 1: Typical Field Reconnaissance Form

embankment and structure foundations. Typical boring programs for highways on new location are established such that basic information is first gathered along the entire highway alignment and subsequent detailed borings are taken as required at structures or in problem embankment areas disclosed by the initial basic program. Subsurface explorations for widening or improvements of existing highways generally are done in one stage as location is predetermined.

2.6 GENERAL HIGHWAY EXPLORATIONS

Embankments are less sensitive than structures to variations in subsurface conditions. Embankment loads are spread over a wide area while structure loads are concentrated. Designers of highways in cut sections are less concerned with deep exploration of subsurface conditions than defining the properties of the soil or rock on which the subgrade materials will be placed. The subsurface exploration program for embankments or cuts must be necessarily widely spaced as the major portion of a highway alignment is one or the other. This section of the manual will deal primarily with approach embankments. Highway embankment and cut explorations are done using the same procedures, but the spacing and depth of borings vary. FHWA Demonstration Project 12, “Soils Exploration and Testing”, suggests that general spacings for embankment or cut borings be 200 to 400 feet with at least one boring in each landform. Highway embankment borings are generally extended to a depth equal to either twice the embankment height or based on landform type and geologic conditions. Cut borings are extended at least 15 feet beyond the anticipated depth of cut at the ditch line. Soft ground conditions at the location of highway embankments or cuts may require additional borings or special testing using methods to be described below.

Approach embankments require more detailed exploration than other highway embankment areas as stability and settlement values must be established before structure foundation design. Typically, test borings (drill holes) are taken for the approach embankment and located at proposed abutment locations to serve a dual function. The depth of the boring will usually be determined by criteria established for the structure design which is described in the following section. In all cases, a boring will extend a distance into competent soil or rock. Additional shallow explorations (auger holes) are commonly taken at approach embankment locations to explore the depth of any suspected unsuitable surface soils or determine topsoil thickness. Additional detailed guidance is available in FHWA-ED-88-053, "Checklist and Guidelines for Review of Geotechnical Reports". Various types of commonly used explorations are shown in Table 2 – 1. The objectives of either deep or shallow borings is to obtain information and samples necessary to define soil and rock subsurface conditions as follows:

1. Stratigraphy.
    a. Physical description and extent of each stratum.
    b. Thickness and elevation of various locations of top and bottom of each stratum.

2. For cohesive soils (each stratum).
    a. Natural moisture contents.
    b. Atterberg limits.
    c. Presence of organic materials.
    d. Evidence of desiccation or previous soil disturbance, shearing, or slickensides.
    e. Swelling characteristics.
    f. Shear strength
    g. Compressibility

3. For granular soils (each stratum).
    a. In-situ density (average and range) typically determined from Standard Penetration Tests or Cone Tests.

   b. Grain-size distributions (gradation).
   c. Presence of organic materials.

4. Ground water (for each aquifer if more than one is present).
   a. Piezometric surface over site area, existing, past, and probable range in future (observe at several times).
   b. Perched water table.

5. Bedrock
   a. Depth over entire site.
   b. Type of rock.
   c. Extent and character of weathering.
   d. Joints, including distribution, spacing, whether open or closed, and joint infilling.
   e. Faults.
   f. Solution effects in limestone or other soluble rocks.
   g. Core recovery and soundness (RQD).

Numerous tools exist for sampling soils including the Pitcher sampler, the Dennison sampler, and drive samplers or augers. When soft ground is encountered, field (in situ) testing and/or undisturbed sample explorations should be done. The use and limitations of undisturbed sampling equipment and in situ testing are respectively shown in Tables 2 – 1 and 2 – 2.

TABLE 2 – 1
SUBSURFACE EXPLORATION – EXPLORATORY BORING METHODS

Method	Use	Limitations
Auger Boring ASTM D – 1452	Obtain samples and identify changes in soil texture above water table. Locate groundwater.	Grinds soft particles – stopped by rocks, etc.
Test Boring ASTM D – 1586	Obtain disturbed split spoon samples for soil classification. Identify texture and structures; estimate density or consistency in soil or soft rock using SPT (N).	Poor results in gravel hard seams.
Thin Wall Tube ASTM D – 1587	Obtain 2” to 3-3/8” diameter undisturbed samples of soft-firm clays and silts for later lab testing.	Cutting edge wrinkled in gravel. Samples lost in very soft clays and silts below water table.
Stationary Piston Sampler	Obtain undisturbed 2” to 3-3/8” diameter samples in very soft clays. Piston set initially at top of tube. After press is completed, any downward movement of the sample creates a partial vacuum which holds the sample in the tube.	Cutting edge wrinkled in gravel.
Pits, Trenches	Visual examination of shallow soil deposits and man made fill above water table. Undisturbed block samples may be extracted.	Caving of walls, ground water.

When additional undisturbed sample borings are taken, the undisturbed samples are sent to a soils laboratory for testing. Drilling personnel should exercise great care in extracting, handling, and transporting these samples to avoid disturbing the natural soil structure. Tubes should only be pressed, not driven with a hammer. The length of press should be 4 to 6 inches less than the tube length (DO NOT OVERPRESS). A plug composed of a mixture of bees wax and paraffin should be poured to seal the tube against moisture loss. The void at the upper tube end should be filled with sawdust and then both ends capped and taped before transport. The most common sources of disturbance are rough, careless handling of the tube (such as dropping the tube samples in the back of a truck and driving 50 miles over a bumpy road), or temperature extremes (leaving the tube sample outside in below zero weather or storing in front of a furnace). Proper storage and transport should be done with the tube upright and encased in an insulated box partially filled with sawdust or styrofoam to act as a cushion. Each tube should be physically separated from adjacent tubes like bottles in a case. An alternate method to ease transportation and storage problem is to extrude the soil from the tube in the field. These samples should be carefully sectioned in 6 to 8 inch lengths, wrapped in wax paper and sealed in a cardboard container (such as ice cream cartons) using liquid paraffin.

TABLE 2 – 2
SUBSURFACE EXPLORATION IN SITU TESTS

Type of Test	Best Suited For	Not Applicable	Properties That Can be Determined	Remarks
A. Routine Accepted Tests*				
Standard Penetration Test (SPT) AASHTO T – 206	Sand, Clay	Gravel	Qualitative evaluation of compactness. Qualitative comparison of subsoil stratification. Estimate of Friction Angle, φ.	Test best suited for sands. Estimated of clay shear strength are crude & should not be used for design.
Dynamic Cone Test	Sand, Gravel	Clay	Qualitative evaluation of compactness. Qualitative comparison of subsoil stratification	FHWA TS-78-209
Static Cone Test ASTM D3441	Sand, Clay	--	Continuous evaluation of density and strength of sands and gravels. Evaluation of pore pressure and undrained shear strength in clays.	Use piezo-cone for pore pressure data. Tests in clay are reliable only when used in conjunction with vane tests. FHWA SA-91-043
Vane Shear Test AASHTO T-223	Clay	Silt, Sand, Gravel	Undrained shear strength, C_u.	Test should be used with care particularly in fissured, varved and highly plastic clays. Extract sample of material tested.
Permeability Test	Sand, Gravel	Clay	Evaluation of Coefficient of Permeability	Variable head test in boreholes have limited accuracy. Results reliable to one order to magnitude are obtained only from long-term, large scale pumping tests.
B. Recently Developed Tests				
Pressure-meter Test ASTM D4719	Soft rock, Sand, Clay	--	Ultimate bearing capacity and compressibility	Requires highly skilled field personnel (FHWA IP-89-008)
Borehole Shear Devices	Sand, Soft Clay	Stiff Clay	Shear Strength	(See FHWA RD-81-1109)
Dilatometer	Sand, Clay	--	Average grain size, Horizontal stress, soil stiffness.	Introduce in USA in 1981 (see ASCE Geot. Journal 3/80 and FHWA SA-91-044).

*(Table based on Canadian Foundation Engineering Manual)

2.7 PROCEDURE FOR SHELBY TUBE SAMPLING

The following procedure was prepared by the New York DOT and modified by the Oregon DOT for successful undisturbed tube sampling. This procedure should be included in agency standards and specifications for undisturbed sampling performed by contract drillers.

General Purpose:

Thin wall tube samples (Shelby tube) are taken to obtain undisturbed samples for laboratory testing to obtain the strength and settlement properties of fine-grained soils containing silt and clay and in some cases organic material. It is extremely important that the samples be pressed and transported with a minimum amount of disturbance. Poor sampling practices, exposure to extreme temperatures and careless handling of samples causes misleading test results that could result in uneconomical designs.

Sampling procedures will be the same regardless of size of Shelby tube. A serious attempt should be made to minimize the length of time between sample procurement and delivery to the central lab. If at all possible, samples should be shipped to the lab the day following procurement of the sample in the field. Careful handing is of utmost importance for geotechnical design units to have reliable information. This careful handling begins with receiving the Shelby tubes from the manufacturer.

1. Receiving Shelby tubes:

   Shelby tubes are received from the manufacturer packed several to the box. Upon receipt, the tubes should be removed from the container immediately and plastic caps put on both ends to prevent damage to these ends from subsequent handling. The tubes should then be stored in an area by themselves, out of the weather, at room temperature, and kept in a horizontal position. Tubes sent from the manufacturer generally have a light film of oil on all surfaces. If not, then a thin coat of oil (such as WD-40) should be applied. This will prevent rust from forming which could affect the sample quality.

2. Transportation of tubes to and from the field:

   Shelby tubes should be placed in a Shelby tube rack as provided by the central lab whenever they are transported to and from the field, whether they are full or empty. Figure 2-2 shows an example of a Shelby tube rack. This rack is to be maintained in a vertical position at all times and all full tubes will remain in the rack until removed by the lab technicians. Transportation to and from the field should be done with the tubes kept inside a vehicle where room temperature can be maintained at all times if possible.

3. Cleaning out the hole:

   The hole should be cleaned out thoroughly before sampling. Clean-out should be done with a clean-out jet type auger for the last 6". In very soft soils, only side discharge auger bits should be used. Bottom discharge bits may cause jet holes in the center of the sample.

   Whenever possible, hollow stem augers should be used for minimum soil disturbance below the bit. At shallow depths hand auger equipment can be utilized to advance the hole.

4. Rate of press:

Shelby tubes should be advanced by a smooth continuous operation. A continuous fast press may be used taking less than 5 seconds. Under no circumstances should a 30" tube be advanced more than 24" to allow for loose material in the hole. For soft soils, wait 5 to 15 minutes before rotating the sampler to shear the end of the sample. For firm soils, a waiting period may not be required. A 360-degree rotation of the drill rod and sample is mandatory to shear the soil at the tube tip elevation.

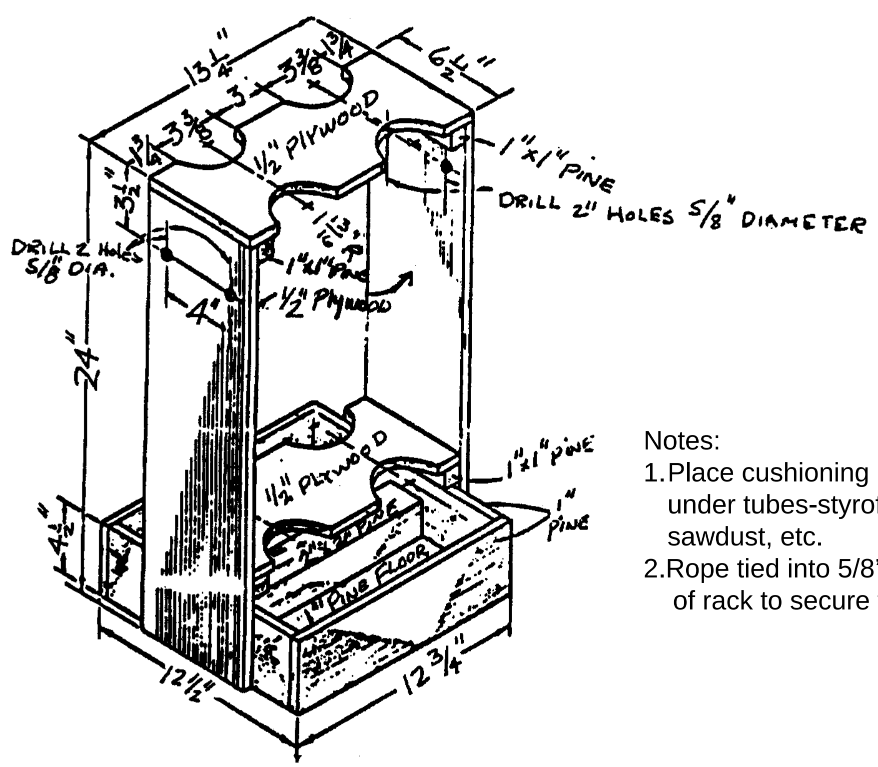
5. Recovery of tube:

The Shelby tube, after shearing, should be recovered from the hole in much the same manner it was pressed into the hole--with a smooth continuous motion with no jerking.

6. Tube preparation (Figure 2-3):

Preparation of the Shelby tube for transport to the lab is very critical and meticulous care must be taken to the fine details of this part of the operation.

The thin wall tube is carefully removed from the sampler head. The tip or bottom of the sampler is scraped smooth so there is no disturbance of the material inside of the tube. The tube is then placed into a holder with the same orientation to vertical as when the sample was taken. A mixture of 50% paraffin and 50% beeswax is melted ahead of time for use in sealing the tube. The top of the tube is cleared of loose material so that the wax is poured on a reasonably smooth soil surface. A wax plug approximately 1/4" thick is poured into the tube by using a funnel in order to keep wax off the sides of the tube. This plug is allowed to set up and then another 1/4" thick layer is poured on top of that. This reduces the shrinkage factor.



Notes:
1. Place cushioning material under tubes-styrofoam or sawdust, etc.
2. Rope tied into 5/8'' holes at top of rack to secure top of tubes

Figure 2-2: Shelby Tube Rack

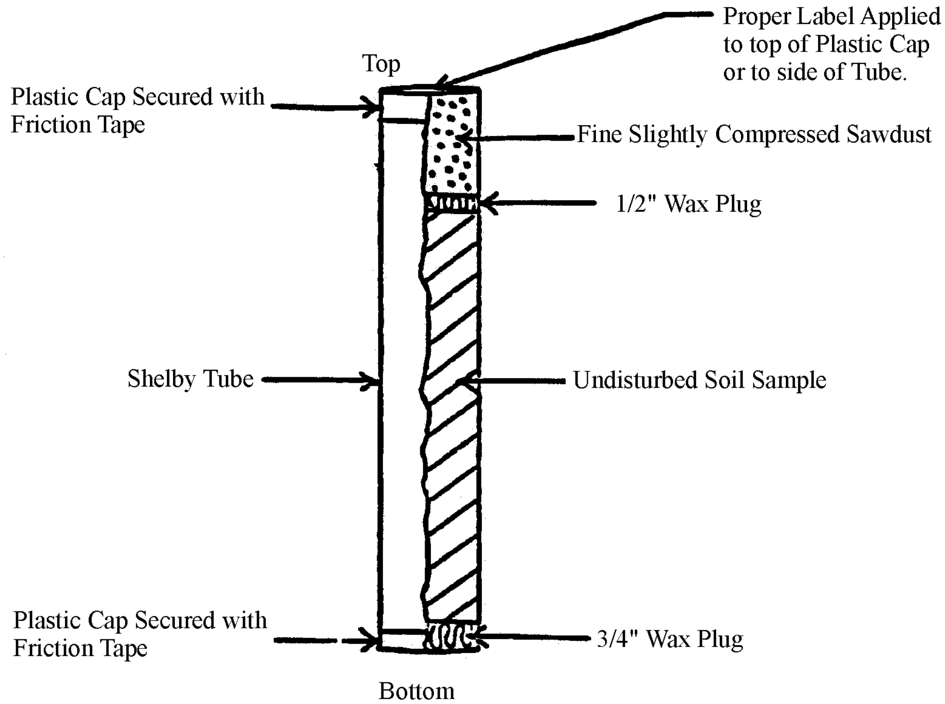


Figure 2-3: Shelby Tube Preparation

After the wax sets up, the remainder of the open tube is filled with fine, lightly compressed sawdust. The end of the tube is then capped with a plastic cap and secured with friction tape. Print the hole number and sample number on top cap with magic marker. This is a precaution against label being lost.

The tube is then turned upside down and the bottom end is prepared for sealing. Approximately 3/4" of material is scraped out of the end of the tube, leaving a smooth surface. The material removed is put into a moisture sample jar or can for further testing. An approximately 3/8" thick plug of wax is poured over the soil. When this plug sets up, the remainder of the tube is filled with wax. When this wax sets up, a plastic cap is fitted over the end and secured with friction tape.

An identification label should be taped to the side of the tube or onto the top cap. The label should include the project identification number, sample number, project name, hole number, station, offset, depth of sample, depth pressed, recovery, and any remarks by the driller.

The tube is then placed into its rack in proper vertical orientation (cutting the edge) and stored inside at room temperature until shipment.

Sealing of samples taken in wet weather should be done under an overhead shelter, as the rain or moisture might affect the quality of the samples taken.

7. Tube shipment to lab:

When all samples have been taken or when the tube rack is full, care must be taken to make sure that the samples are not exposed to extreme cold (freezing) or heat. The best method for this is to completely fill the tube rack with fine sawdust prior to shipping, and to ship in a vehicle where room temperature can be maintained.

2.8 STANDARD PENETRATION TEST (SPT)

Probably the most widely used field test in the United States is the Standard Penetration Test (SPT). This test has been standardized in both AASHTO T-206 and ASTM D-1586. SPT testing is recommended for all drill holes taken on highway projects due to the simplicity and economy of the test and the usefulness of the data obtained. In this test, a measure of soil density and a soil sample are obtained in the following manner. After the boring is cleaned out, the standard split-spoon sampler is attached to a set of drill rods and lowered to the bottom of the hole. Attached to the upper end of the drill rod is a 140-pound hammer which can be hand operated. The test consists of driving the split-spoon sampler 18 inches with the 140-pound hammer falling through a drop of 30 inches. The first 6-inch increment is referred to as the seating load. The sum of the next two 6-inch increments is known as the Standard Penetration Value (N). The soil sample obtained is disturbed, but can be used for visual classification. The sample is normally tightly sealed in a jar and sent to the laboratory where routine tests such as natural water content, gradation analyses, and Atterberg Limits can be conducted.

The N-values of this test are an indication of the density of cohesionless soils and the consistency of cohesive soil. General N-value ranges versus density and consistency are shown below in Table 2-3. It is emphasized that for gravels and clays these are rather unreliable and should only serve as general estimates.

TABLE 2 – 3
SOIL PROPERTIES CORRELATED WITH STANDARD PENETRATION TEST VALUES*

Sands (Reliable)		Clays (Rather Unreliable)	
Number of Blows per ft, N	Relative Density	Number of Blows per ft, N	Consistency
0-4	Very loose	Below 2	Very soft
5-10	Loose	2-4	Soft
11-30	Medium Dense	5-8	Medium
31-50	Dense	9-15	Stiff
Over 50	Very dense	16-30	Very stiff
		Over 30	Hard

*Measured with 1-3/8" I.D., 2" O.D. sampler driven by 140# hammer falling 30".
*Sections 6.3.2 and 7.2.1 contain additional information on the uses of SPT values to estimate engineering properties.

2.8.1SPT Test Errors

Although the procedures have been standardized for conducting the SPT test, several errors can creep into the test. The most common errors are:

1. Effect of overburden pressure. Soils of the same density will give smaller counts near the ground surface.

2. Variations in the 30-inch free fall of the drive weight, since this is often done by eye on older equipment using a rope wrapped around a power takeoff (cathead) from the drill motor. Newer automatic hammer equipment does this automatically.

3. Interference with the free fall of the drive weight by the guides or the hoist rope. New equipment eliminates rope interference.

4. Use of a drive shoe that is badly damaged or worn from too many drivings to "refusal" (blow count exceeding 100).

5. Failure to properly seat the sampler on undisturbed material in the bottom of the boring.

6. Inadequate cleaning of loosened material from the bottom of the boring.

7. Failure to maintain sufficient hydrostatic pressure in the borehole during drilling. Unbalanced hydrostatic pressures between the borehole drill water and the ground water table can cause the test zone to become "quick." This can happen when using the continuous-flight auger with the end plugged and maintaining a water level in the hollow stem below that in the hole.

8. SPT results may not be dependable in gravel. Since the split-spoon inside diameter is 1-3/8 inches, gravel sizes larger than 1-3/8 inches will not enter the spoon. Therefore, soil descriptions may not reflect actual gravel content of the deposit. Also, gravel pieces may plug the end of the spoon and cause the SPT blow count to be erroneously high.

9. Samples retrieved from dilatant soils (fine sands, sandy silts) which exhibit unusually high blow count should be examined in the field to determine if the sampler drive shoe plugged. Look for poor sample recovery as an indication of plugging.

10. Careless work on the part of the drill crew.

THE USE OF RELIABLE QUALIFIED DRILLERS CANNOT BE OVEREMPHASIZED. AGENCIES WHICH MAINTAIN THEIR OWN DRILLING PERSONNEL AND EQUIPMENT ACHIEVE MUCH MORE RELIABLE, CONSISTENT RESULTS THAN THOSE WHO ROUTINELY LET BORING CONTRACTS TO THE LOW BIDDER.

Studies show that soil type, density, and overburden pressure are the most significant factors affecting "N" (assuming good workmanship and equipment).

Regardless of the impressive list of shortcomings, the SPT is not likely to be abandoned for several reasons:

1. The test is very economical in terms of cost per unit of information.
2. The test results in recovery of soil samples, which can be tested for index properties and visually examined.
3. Long service life of the enormous amount of equipment in use.
4. The accumulation of a large SPT database which is continually expanding.
5. The fact that other methods can be readily used to supplement the SPT when the borings indicate more refinement in sample/data collection.

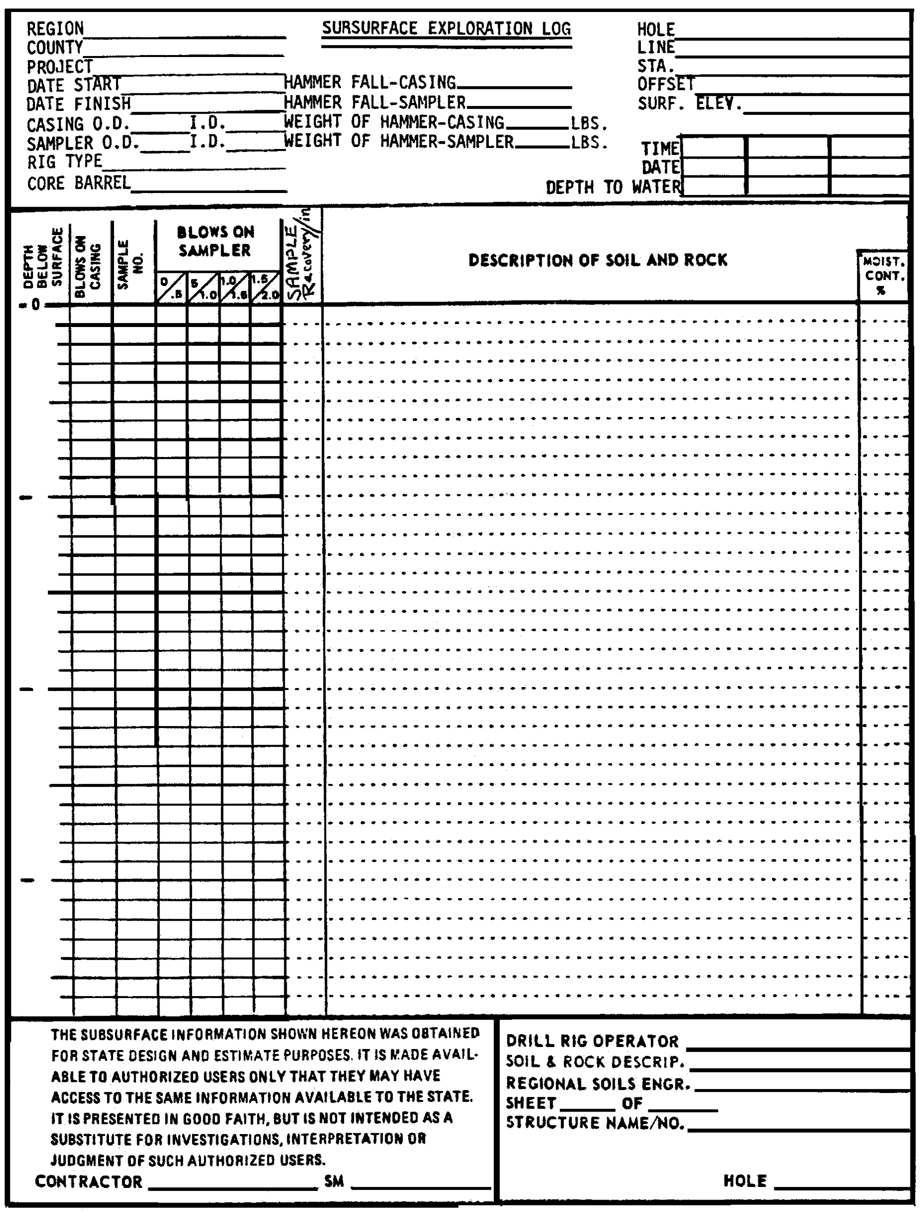
2.9 FIELD BORING LOG

The importance of good logging and field notes cannot be overemphasized. The logger must realize that a good field description must be recorded. The field-boring log is the major portion of the factual data used in the analysis of foundation conditions.

The log is a record which should contain all of the information obtained from a boring whether or not it may seem important at the time of drilling. It is important to record the maximum amount of accurate information. This record is the "field" boring log, as opposed to the "finished" boring log used in the preparation of the final report made to the designer. The finished log is drawn from the data given in the field log supplemented by the results of lab visual identification of samples and lab classification tests. A typical boring log form which can be used for recording both field and finished data is shown on Figure 2-4.

The person who actually logs the field information will vary from organization to organization. Some will have an engineering geologist, or trained technician accompany the drill crew, while others may train the drill crew foreman to log the borehole. In order to obtain the maximum amount of accurate data, the logger should work closely with the driller and be alert for changes in materials and operations while drilling.

SUBSURFACE EXPLORATION LOG


REGION
COUNTY
PROJECT
DATE START
DATE FINISH
CASING O.D. I.D.
SAMPLER O.D. I.D.
RIG TYPE
CORE BARREL

SUBSURFACE EXPLORATION LOG
HAMMER FALL-CASING
HAMMER FALL-SAMPLER
WEIGHT OF HAMMER-CASING LBS.
WEIGHT OF HAMMER-SAMPLER LBS.

HOLE
LINE
STA.
OFFSET
SURF. ELEV.
TIME
DATE
DEPTH TO WATER

DEPTH BELOW SURFACE	BLOWS ON CASING	SAMPLE NO.	BLOWS ON SAMPLER 0/.5	.5/1.0	1.0/1.5	1.5/2.0	SAMPLE Recovery/in	DESCRIPTION OF SOIL AND ROCK	MOIST. CONT. %
0									

THE SUBSURFACE INFORMATION SHOWN HEREON WAS OBTAINED FOR STATE DESIGN AND ESTIMATE PURPOSES. IT IS MADE AVAILABLE TO AUTHORIZED USERS ONLY THAT THEY MAY HAVE ACCESS TO THE SAME INFORMATION AVAILABLE TO THE STATE. IT IS PRESENTED IN GOOD FAITH, BUT IS NOT INTENDED AS A SUBSTITUTE FOR INVESTIGATIONS, INTERPRETATION OR JUDGMENT OF SUCH AUTHORIZED USERS.
CONTRACTOR SM

DRILL RIG OPERATOR
SOIL & ROCK DESCRIP.
REGIONAL SOILS ENGR.
SHEET OF
STRUCTURE NAME/NO.
HOLE

Figure 2 – 4: Subsurface Exploration Log

Duties of the Logger:

Generally, the logger should be responsible for recording the following information on the field boring log:

1. General description of each rock and soil stratum, and the depth to the top and bottom of each stratum.

2. The depth at which each sample is taken, the type of sample taken, its number, and any loss of samples taken during extraction from the hole.

3. The depths at which field tests are made and the results of the test.

4. Information generally required by the log format, such as:

   - Boring number and location.
   - Date of start and finish of the hole.
   - Name of driller (and of logger, if applicable).
   - Elevation at top of hole.
   - Depth of hole and reason for termination.
   - Diameter of any casing used.
   - Size of hammer and free fall used on casing (if driven).
   - Blows per foot to advance casing (if driven).
   - Description and size of sampler.
   - Size of drive hammer and free fall used on sampler in dynamic field tests.
   - Blow count for each 6 inches to drive sampler. (Sampler should be driven three 6-inch increments or to 100 blows).
   - Type of drilling machine used.
   - Type and size of core barrel used.
   - Length of time to drill each core run or foot of core run.
   - Length of each core run and amount of core per run.
   - Recovery of sample in inches and RQD of rock core.
   - Project identification.

5. Notes regarding any other pertinent information and remarks on miscellaneous conditions encountered, such as:

   - Depth of observed groundwater, elapsed time from completion of drilling, conditions under which observations were made, and comparison with the elevation noted during reconnaissance (if any).
   - Artesian water pressure.
   - Obstructions encountered.
   - Difficulties in drilling (caving, coring boulders, surging or rise of sands in casing, caverns, etc.).
   - Loss of circulating water and addition of extra drilling water.
   - Drilling mud and casing as needed and why.
   - Odor of recovered sample.
   - Sampler plugged.
   - Poor recovery.

6. Any other information the collection of which may be required by highway agency policy.

2.10 GUIDELINES FOR MINIMUM SUBSURFACE EXPLORATION PROGRAM

In regard to the scope of the subsurface program for a structure, one must carefully consider the small cost of a boring in relation to the foundation cost. A 2½ - inch diameter drill hole will cost less than one 12-inch diameter pile. Yet the knowledge gained from that boring will permit proper design techniques to be used which may allow elimination of all piles for that structure. Without adequate boring data, the foundation design engineer cannot utilize his technique or experience and must rely on extremely conservative designs with high safety factors.

Planning a soils or foundation exploration program should include determining the depth and location of borings, test pits, or other procedures to be used and establishing the methods of soil sampling and testing to be employed. Usually, the extent of the work is established as it progresses, unless knowledge of foundation conditions is available from geological studies, earlier investigations, or records of existing structures. The number, depth, spacing, and character of tests to be made in any individual exploration program are so dependent upon site conditions, type of structure, and its requirements, that no rigid rules may be established. However, certain general principles for the guidance of those charged with the investigation can be outlined.

The following program will produce the minimum foundation data for a typical structure site. Soft ground conditions may require undisturbed sample explorations or in situ testing as previously mentioned.

1. Progress one minimum 2½ - inch diameter drill hole at each pier or abutment, and at the end of any wingwall which measures over 30 feet in length. The hole pattern should be staggered at the opposite ends of adjacent footings. Piers or abutments over 100 feet in length require one 2½ - inch drill hole at the extremities of each element. The drill holes may be advanced with casing, drilling mud, or continuous flight augers. For proposed spread footing design on sloping rock surfaces, additional borings and probe holes may be required.

2. Estimate the boring depth from existing data obtained during the terrain reconnaissance phases or, less preferred, from requested boring resistance data such as: "The borings for structure foundations shall be terminated when a minimum resistance criteria of 20 blows per foot on the sample spoon has been achieved for 20 feet of drilling," or "the boring shall extend 10 feet into rock having an average recovery of 50 percent or greater." The minimum resistance criteria may be modified depending on the deep foundation capacity anticipated at the site.

3. Obtain standard split spoon samples at 5-foot intervals or at changes in material. Continuous spoon samples are recommended for the top 15 feet where footings may be placed on natural soil. These spoon samples are "disturbed" samples generally not suited for laboratory determination of strength or consolidation parameters. Undisturbed Shelby tube samples should be obtained at 5-foot intervals in at least one boring in cohesive soils. For cohesive deposits greater than 30 feet in depth, tube sample interval can be increased to 10 feet. In soft clay deposits in situ vane shear strength tests are recommended at 5-10 foot intervals.

4. Record the standard penetration test data for each drill hole in accordance with ASTM D-1586. The SPT test is the most economical method presently available of procuring useful data regardless of the often cited frailties of the test.

5. Instruct the drilling crew to perform a rough visual analysis of the soil samples and record all pertinent data on a standard drill log form. The disturbed spoon samples must be carefully sealed in plastic bags, placed in jars, and sent to the laboratory for analysis. Undisturbed tube samples must be sealed and

stored upright in a shock proof, insulated container normally constructed from plywood and filled with cushioning material.

6. Observe the water level in each boring and record the depth below top of hole and the date of the reading on the drill log for:

   a. Water seepage or artesian pressure encountered during drilling. Artesian pressure may be measured by extending drill casing above the ground until flow stops. Report the pressure as the number of feet of head above ground.

   b. Water level at the end of each day and at completion of boring.

   c. Water level 24 hours (minimum) after hole completion. Long term readings may require installation of a perforated plastic tube before abandoning the hole.

   A false indication of water level may be obtained when water is used in drilling and adequate time is not permitted after hole completion for the water level to stabilize. In low permeability soils, such as clays, more than one week may be required to obtain accurate readings.

7. Designate a unique identification number for each drill hole to prevent duplication during later exploration phases. Much confusion has resulted on projects where exploration numbering was done by only single numbers. It was not unusual to have several drill holes numbered DH-1 on the same project. A suggested method to avoid duplication is to designate that all bridge holes begin with the letter "B", followed by the initials of the highway or river being crossed and finally a sequential number, i.e., the first hole for the Apple Freeway structure would be designated DH-BAF-1.

The reasons for obtaining this minimum data are clear; the engineer must have adequate data to determine the soil type and relative compactness, and the position of the static water level. Methods such as driving open-end rod without obtaining soil samples or water level readings taken after the last soil sample was removed must be discouraged. Good communication between the driller and the foundation engineer is essential during all phases of the subsurface investigation program.

2.11 APPLE FREEWAY DESIGN EXAMPLE – SITE EXPLORATION

In each chapter various pertinent aspects of the design process as outlined in Section 1.3 are demonstrated through a fictitious bridge project named “Apple Freeway Project.” The plan and cross section of the fictitious bridge and approaches are shown in Figure 2 – 5. The following design example presents the process of planning a site exploration program for Apple Freeway Project.

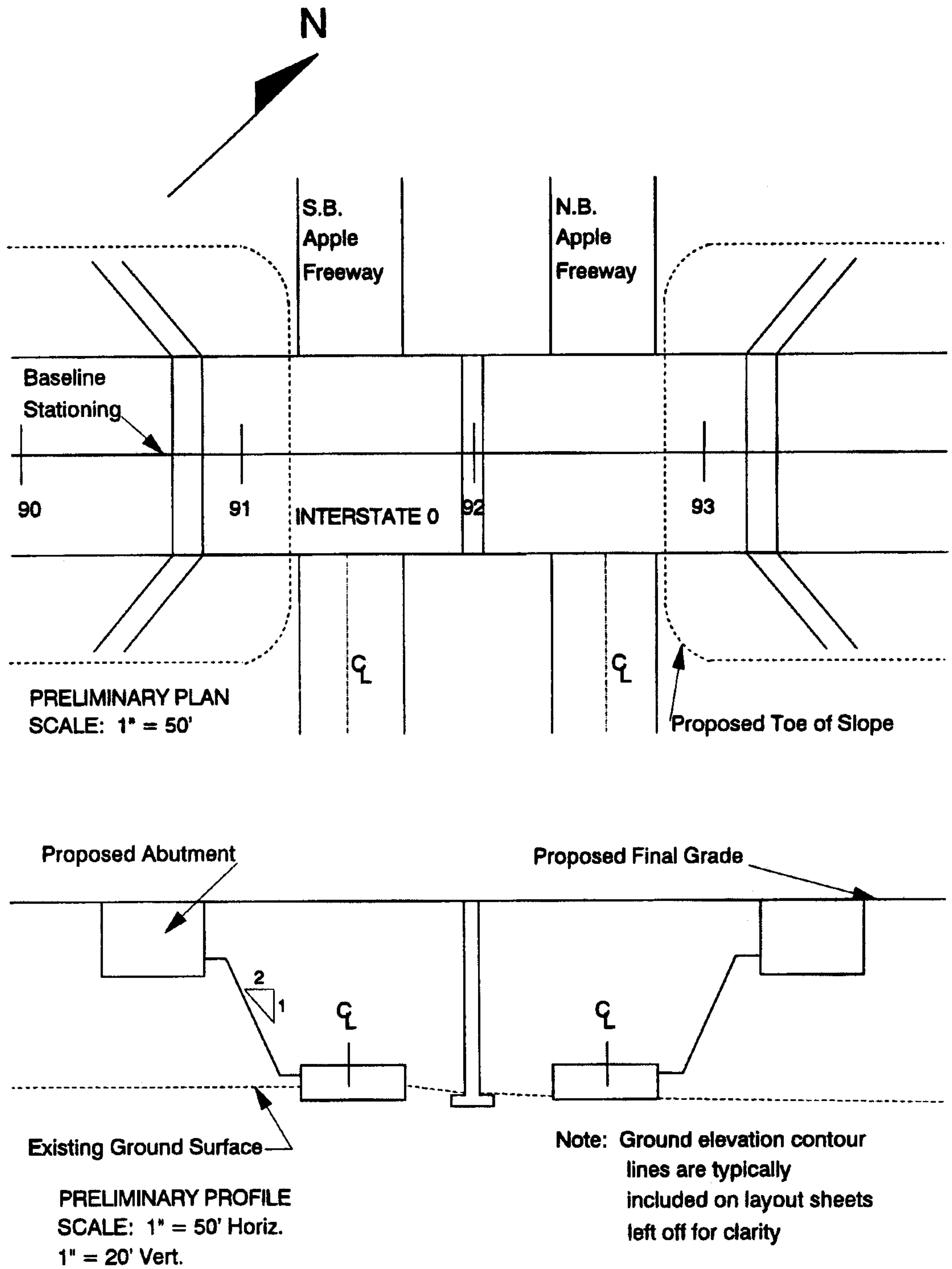


Figure 2 – 5: Apple Freeway Plan and Section

Site Exploration

Terrain Reconnaissance
Site Inspection
Subsurface Borings

Basic Soil Properties	Visual Description Classification Tests Soil Profile
Laboratory Testing	Po Diagram Test Request Consolidation Results Strength Results
Slope Stability	Design Soil Profile Circular Arc Analysis Sliding Block Analysis Lateral Squeeze
Embankment Settlement	Design Soil Profile Settlement Time – Rate Surcharge Vertical Drains
Spread Footing Design	Design Soil Profile Pier Bearing Capacity Pier Settlement Abutment Settlement Vertical Drains Surcharge

Pile Design	Design Soil Profile
	Static Analysis – Pier
	    Pipe Pile
	    H – Pile
	Static Analysis – abutment
	    Pipe Pile
	    H – Pile
	Driving Resistance
	Abutment Lateral Movement

Construction Monitoring	Wave Equation Hammer Approval Embankment Instrumentation

Apple Freeway Design Example – Site Exploration
Exhibit A

LAYOUT OF SUBSURFACE EXPLORATION PROGRAM

Given: Soil map showed structure to be located in a delta landform. Field inspection showed wet area with cattails in vicinity of East abutment.

Required: Plan subsurface exploration program and prepare boring request.

Solution:

Step 1: **Identify boring types required and location established (see exhibit B).**

- Disturbed SPT sample boring at each abutment and intermediate support
- Hand Auger holes in wet area within East approach fill limits

Step 2: **Establish criteria for determining boring depth.**

- SPT holes to depth where the minimum N average equals 20 for 20′ depth or 10′ into bedrock whichever depth is less.
- Hand auger holes to a maximum depth of 10′ or at least 3′ below bottom of unstable soils (soft and/or organic soils) whichever depth is less.

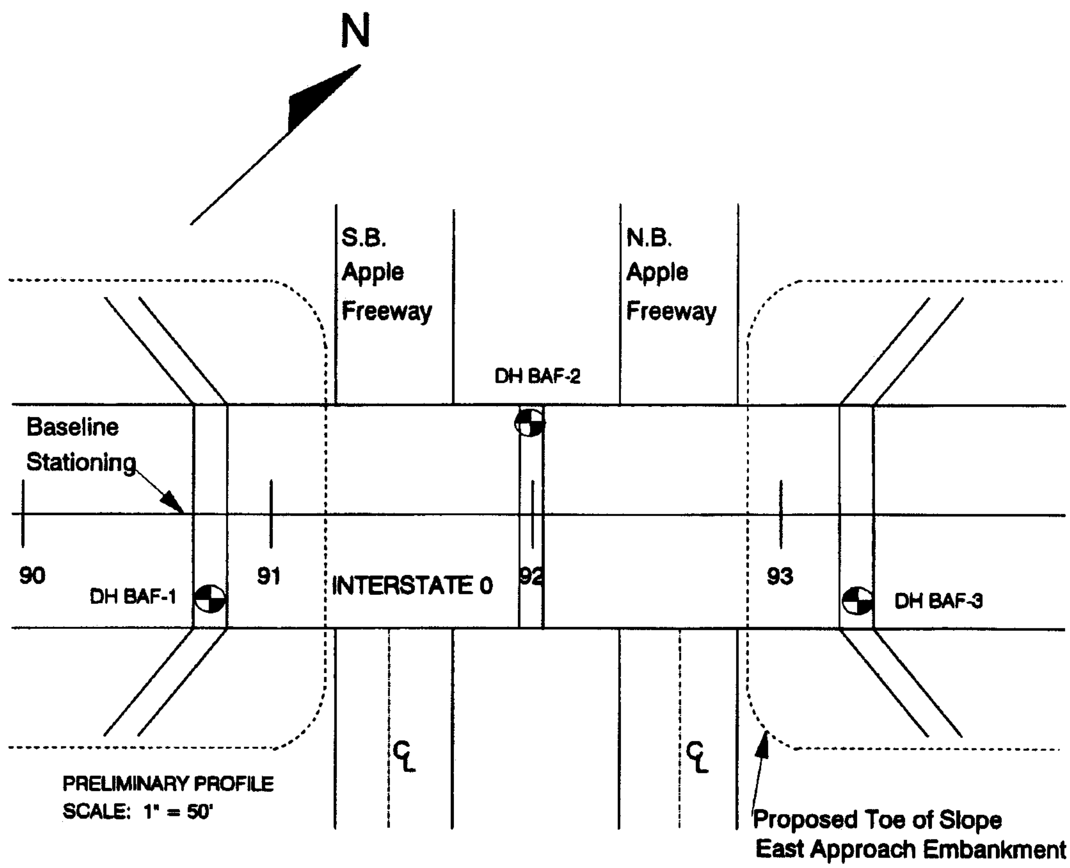
Step 3: **Establish sampling criteria**

- East and West abutments: Disturbed SPT every 5′.
- Pier footing: Continuous SPT samples to depth of 15′, then 5′ intervals.
- Wet area: obtain representative samples in each auger hole.

Step 4: **Identify other important consideration.**

- Since area is a delta landform, granular deposits overlying clay may be encountered. If so, an undisturbed drill hole (UDH) will be required. The location, depth, and sampling details will be selected based on the results of the three SPT boring. Notify the drillers of possibility of UDH and vane shear so necessary equipment can be taken to site. Long-term water level reading should be taken in one hole.

Step 5: **Prepare boring request (see exhibit C).**



Apple Freeway Design Example – Site Exploration
Exhibit B - Proposed Site Explorations

WORKSHOP DESIGN EXAMPLE
BORING REQUEST

March 1, 1992

Subject: Request for Subsurface Investigation
Interstate Structure over the Apple Freeway

From: Foundation Engineer

To: Regional Office

In accordance with project authorization from the Chief Engineer dated January 16, 1992, a subsurface investigation program has been prepared for the subject structure. We request that your office progress a 2½ - inch diameter cased drill hole at each of the following locations:

Hole No.	Baseline Station	Offset (ft)
DH-BAF-1	90 + 77	50' Rt
DH-BAF-2	92 + 00	50' Lt
DH-BAF-3	93 + 27	50' Rt

The locations may be field adjusted along the footing line shown on the attached drawing if necessary.

Each boring shall extend to a depth where the blow count per foot on the sample spoon has exceeded 20 for a 20' depth. If rock is encountered above this depth, 10 feet of rock core shall be extracted. Spoon samples shall be taken at intervals of 5-feet except for the top 15 feet of BAF-2 where continuous spoon samples are required. On completion of BAF-2 a perforated plastic pipe should be inserted before extracting the casing to permit long-term water level observation. It is anticipated that soft clay soils may be encountered at this site. If so, an additional 4-inch diameter cased hole may be required to extract undisturbed tube samples and/or perform in situ vane shear tests. Before the drill crew demobilizes, the driller should telephone the results of the first three SPT borings to the project engineer, Mr. Richard Cheney at 202-426-0355. At that time, a decision on the details of the UDH will be issued.

A wet area of potentially unstable soil (soft and/or organic soils) exists in the area of the proposed east approach embankment. Please define the depth of this deposit beneath the limits of the east approach embankment back to Baseline station 93 + 50 with hand auger exploration.

The present schedule for structure design requires that all samples and subsurface logs be received in the main office by July 1, 1992.

Attachment: Proposed site exploration plan

Apple Freeway Design Example – Site Exploration
Exhibit C – Typical Boring Request

REGION 3
COUNTY Orange
PROJECT Interstate 0
DATE START 5/2/92
DATE FINISH 5/3/92
CASING O.D. 2-1/2" I.D.
SAMPLER O.D. 2" I.D. 1-3/8"
RIG TYPE Acker B-40
CORE BARREL Double Tube

SUBSURFACE EXPLORATION LOG

HAMMER FALL-CASING 18"
HAMMER FALL-SAMPLER 30"
WEIGHT OF HAMMER-CASING 300 LBS.
WEIGHT OF HAMMER-SAMPLER 140 LBS.

HOLE BAF-1
LINE Baseline
STA. 90+77
OFFSET 50' Rt.
SURF. ELEV. 1001.1

TIME	4 pm	8 am	
DATE	5/2/92	5/3/92	
DEPTH TO WATER	15'	15'	

DEPTH BELOW SURFACE	BLOWS ON CASING	SAMPLE NO.	BLOWS ON SAMPLER 0/.5	.5/1.0	1.0/1.5	1.5/2.0	Sample/Recovery/in	DESCRIPTION OF SOIL AND ROCK	MOIST CONT %
0	4	J1	1	3	5				10
	16								
	25								
	16								
	20								
	30	J2	7	7	8			GR. FINE TO COARSE SAND	7
	21								
	35							MOIST - NON PLASTIC	
	38								
10	51								
	40	J3	10	21	20				6
	35								
	52								
	58								
	61								
	50	J4	10	18	21				6
	42								
	65								
	72								
20	76							20'	
	60	J5	3	6	6				31
	51								
	72								
	75							GR. SILTY CLAY	
	81								
	80	J6	3	6	7			MOIST - PLASTIC	32
	71								
	90								
	83								
30	84								
	80	J7	2	4	4				36
	77								
	83								
	84								
	86								

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CONTRACTOR ______ SM ______

DRILL RIG OPERATOR Klinedinst
SOIL & ROCK DESCRIP. Chassie
REGIONAL SOILS ENGR. Chenev
SHEET 1 OF 2
STRUCTURE NAME/NO. Apple Freeway #2

HOLE BAF-1

Apple Freeway Design Example – Site Exploration
Exhibit D – Boring Logs

REGION 3
COUNTY Orange
PROJECT Interstate 0
DATE START 5/2/92
DATE FINISH 5/3/92
CASING O.D. 2-1/2" I.D.
SAMPLER O.D. 2" I.D. 1-3/8"
RIG TYPE Acker B-40
CORE BARREL Double Tube

SUBSURFACE EXPLORATION LOG

HAMMER FALL-CASING 18"
HAMMER FALL-SAMPLER 30"
WEIGHT OF HAMMER-CASING 300 LBS.
WEIGHT OF HAMMER-SAMPLER 140 LBS.

HOLE BAF-1
LINE Baseline
STA. 90+77
OFFSET 50' Rt.
SURF. ELEV. 1001.1

TIME	4 pm	8 am	
DATE	5/2/92	5/3/92	
DEPTH TO WATER	15'	15'	

DEPTH BELOW SURFACE	BLOWS ON CASING	SAMPLE NO.	BLOWS ON SAMPLER 0/.5	.5/1.0	1.0/1.5	1.5/2.0	DESCRIPTION OF SOIL AND ROCK	MOIST CONT %
35	80	J8	2	3	3			38
	76						GR. SILTY CLAY	
	85						MOIST - PLASTIC	
	87							
	89						40.5'	
40	81		3	3	50			
	120							
	140						GR. SANDY GRAVEL	
	156							
	180						MOIST - NON PLASTIC	
	160		35	50				
	195							
	200							
	210							
	230						TOP OF ROCK 50'	
50							HARD UNWEATHERED BASALT	
							Run 1 = 60"	
							RECOVERY = 48" RQD = 70%	
							9 PIECES	
							55'	
							HARD UNWEATHERED BASALT	
							RUN 2 = 60" RQD = 80%	
							RECOVERY = 54" 8 PIECES	
60							60'	
							END OF BORING 60'	

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CONTRACTOR ______ SM ______

DRILL RIG OPERATOR Klinedinst
SOIL & ROCK DESCRIP. Chassie
REGIONAL SOILS ENGR. Cheney
SHEET 2 OF 2
STRUCTURE NAME/NO. Apple Freeway #2

HOLE BAF-1

Apple Freeway Design Example – Site Exploration
Exhibit D – Boring Logs (Cont'd)

REGION 3	SUBSURFACE EXPLORATION LOG	HOLE BAF-2
COUNTY ORANGE		LINE Baseline
PROJECT INTERSTATE 0		STA. 92+00
DATE START 5/4/92	HAMMER FALL-CASING 18"	OFFSET 50' Lt.
DATE FINISH 5/6/92	HAMMER FALL-SAMPLER 30"	SURF. ELEV. 996.2
CASING O.D. 2-1/2" I.D.	WEIGHT OF HAMMER-CASING 300 LBS.	
SAMPLER O.D. 2" I.D. 1-3/8"	WEIGHT OF HAMMER-SAMPLER 140 LBS.	
RIG TYPE Acker B-40		
CORE BARREL Double Tube		

	TIME	DATE	DEPTH TO WATER
	4 pm	5/4/92	10'
	8 am	5/6/92	10'

DEPTH BELOW SURFACE	BLOWS ON CASING	SAMPLE NO.	BLOWS ON SAMPLER 0/.5	.5/1.0	1.0/1.5	1.5/2.0	DESCRIPTION OF SOIL AND ROCK	MOIST. CONT. %
0	6	J1	1	2	2			12
	19							
	27	J2	1	3	3		GR - SILTY SAND	8
	35							
	21	J3	2	5	6		MOIST - NON PLASTIC	7
	30	J4	7	9	12			10
	22							
	25	J5	8	7	15			6
	24							
10	28	J6	14	20	20			7
	27	J7	15	18	19			
	36							10
	34	J8	13	16	17			7
	37						14.5'	
	39	J9	15	10	3			34
	31							
	40							
	46							
	46							
20	45							
	41	J10	2	4	4			31
	42						GR. SILTY CLAY	
	56							
	52						MOIST - PLASTIC	
	58							
	50	J11	2	3	3			36
	56							
	52							
	49							
30	58							
	52	J12	1	2	3			37
	56							
	61							
	63							
	65							

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CONTRACTOR ____________ SM ____________

DRILL RIG OPERATOR Klinedinst
SOIL & ROCK DESCRIP. Chassie
REGIONAL SOILS ENGR. Cheney
SHEET 1 OF 2
STRUCTURE NAME/NO. Apple Freeway #2

HOLE BAF-2

Freeway Design Example – Site Exploration
Exhibit D – Boring Logs (Cont'd)

REGION 3
COUNTY ORANGE
PROJECT INTERSTATE 0
DATE START 5/4/92
DATE FINISH 5/6/92
CASING O.D. 2-1/2" I.D.
SAMPLER O.D. 2" I.D. 1-3/8"
RIG TYPE Acker B-40
CORE BARREL Double Tube

SUBSURFACE EXPLORATION LOG

HAMMER FALL-CASING 18"
HAMMER FALL-SAMPLER 30"
WEIGHT OF HAMMER-CASING 300 LBS.
WEIGHT OF HAMMER-SAMPLER 140 LBS.

HOLE BAF-2
LINE Baseline
STA. 92+00
OFFSET 50' Lt.
SURF. ELEV. 996.2

TIME	4 pm	8 am	
DATE	5/4/92	5/6/92	
DEPTH TO WATER	10'	10'	

DEPTH BELOW SURFACE	BLOWS ON CASING	SAMPLE NO.	BLOWS ON SAMPLER 0/.5	.5/1.0	1.0/1.5	1.5/2.0	DESCRIPTION OF SOIL AND ROCK	MOIST. CONT. %
35	62	J13	1	2	4		GR SILTY CLAY	34
	63						MOIST - PLASTIC	
	72							
	71						39'	
40	89							
	75		30	20	35			
	81						GR. SANDY GRAVEL	
	401							
	120						MOIST - NON PLASTIC	
	140						(Cored Boulder 42.5' to 45', recovered 12"-7 pieces:	
	110		50	60			used boulder buster)	
	136							
	166							
	191							
50	482						Top of Rock 50'	
							HARD UNWEATHERED BASALT	
							Run 1 - 60"	
							Recovery - 55" - 13 pieces RQD = 80%	
							55'	
							HARD UNWEATHERED BASALT	
							Run 2 - 60"	
							Recovery - 52" 7 pieces RQD - 75%	
60							60'	
							end of boring 60'	

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CONTRACTOR ____________ SM ________

DRILL RIG OPERATOR Klinedinst
SOIL & ROCK DESCRIP. Chassie
REGIONAL SOILS ENGR. Cheney
SHEET 2 OF 2
STRUCTURE NAME/NO. Apple Freeway #2

HOLE BAF-2

Apple Freeway Design Example – Site Exploration
Exhibit D – Boring Logs (Cont'd)

REGION 3
COUNTY ORANGE
PROJECT INTERSTATE 0
DATE START 5/8/92
DATE FINISH 5/9/92
CASING O.D. 2-1/2" I.D.
SAMPLER O.D. 2" I.D. 1-1/2"
RIG TYPE Acker B-40
CORE BARREL Double Tube

SUBSURFACE EXPLORATION LOG

HAMMER FALL-CASING 18"
HAMMER FALL-SAMPLER 30"
WEIGHT OF HAMMER-CASING 300 LBS.
WEIGHT OF HAMMER-SAMPLER 140 LBS.

HOLE BAF-3
LINE Baseline
STA. 93+27
OFFSET 50' Rt.
SURF. ELEV. 990.0

TIME	4 pm	8 am	
DATE	5/8/92	5/9/92	
DEPTH TO WATER	6'	6'	

DEPTH BELOW SURFACE	BLOWS ON CASING	SAMPLE NO.	BLOWS ON SAMPLER 0-.5	BLOWS ON SAMPLER .5-1.0	BLOWS ON SAMPLER 1.0-1.5	BLOWS ON SAMPLER 1.5-2.0	DESCRIPTION OF SOIL AND ROCK	MOIST. CONT. %
0	0	J1	1	0	1		BLACK MUCK WET - PLASTIC	115
	2						2'	
	11	J2	3	5	7			20
	25							
	31						GR SAND W/ ROOTS AND FIBERS	
	40							
	41	J3	8	8	9		MOIST - NON PLASTIC	8
	56							
	71							
10	83						10'	
	70	J4	6	5	5			29
	91							
	93							
	82						GR-BR CLAYEY SILT	
	93							
	81	J5	2	3	6		MOIST PLASTIC	31
	80							
	87							
	85							
20	90						20'	
	82	J6	4	3	3			34
	86							
	87						GR SILTY CLAY	
	85							
	90						MOIST - PLASTIC	
	73	J7	2	2	3			39
	72							
	83							
	71							
30	61							
	81	J8	2	2	2			40
	83							
	72							
	76							
	83							

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CONTRACTOR ____________ SM ____________

DRILL RIG OPERATOR Klinedinst
SOIL & ROCK DESCRIP. Chassie
REGIONAL SOILS ENGR. Cheney
SHEET 1 OF 2
STRUCTURE NAME/NO. Apple Freeway #2

HOLE BAF-3

Apple Freeway Design Example – Site Exploration
Exhibit D – Boring Logs (Cont'd)

REGION 3
COUNTY ORANGE
PROJECT INTERSTATE 0
DATE START 5/8/92
DATE FINISH 5/9/92
CASING O.D. 2-1/2" I.D.
SAMPLER O.D. 2" I.D. 1-1/2"
RIG TYPE Acker B-40
CORE BARREL Double Tube

SUBSURFACE EXPLORATION LOG

HAMMER FALL-CASING 18"
HAMMER FALL-SAMPLER 30"
WEIGHT OF HAMMER-CASING 300 LBS.
WEIGHT OF HAMMER-SAMPLER 140 LBS.

HOLE BAF-3
LINE Baseline
STA. 93+27
OFFSET 50' Rt.
SURF. ELEV. 990.0

TIME	4 pm	8 am	
DATE	5/8/92	5/9/92	
DEPTH TO WATER	6'	6'	

DEPTH BELOW SURFACE	BLOWS ON CASING	SAMPLE NO.	BLOWS ON SAMPLER 0/.5	.5/1.0	1.0/1.5	1.5/2.0	DESCRIPTION OF SOIL AND ROCK	MOIST. CONT. %
35	71	J9	2	3	2			36
	79						GR SILTY CLAY	
	86							
	83						MOIST — PLASTIC	
	85							
40	82	J10	3	4	3			35
	81							
	93							
	91							
	96						45'	
	121	J11	20	21	35			10
	450						GR SILTY GRAVEL	
	391							
	220						MOIST - NON PLASTIC	
50	230							
	200	J12	15	36	40		52' to 53' CORED BOULDER	5
	370						RECOVERY 3"	
	400						MANY FRAGMENTS	
	410							
	380							
		J13	40	60	80			7
							TOP OF ROCK 60.5'	
60		J14	100	REFUSAL @ 60.5'			60.5'	
							HARD UNWEATHERED BASALT	
							RUN 1 60.5' to 65.5' - 60" - RECOVERY 50", 12 PIECES RQD	70%
							RUN 2 65.5' to 70.5' - 60" - RECOVERY 60", 6 pieces RQD 95%	
							HARD UNWEATHERED BASALT	
70								
							End of Boring 70.5'	

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CONTRACTOR ________ SM ________

DRILL RIG OPERATOR Klinedinst
SOIL & ROCK DESCRIP. Chassie
REGIONAL SOILS ENGR. Cheney
SHEET 2 OF 2
STRUCTURE NAME/NO. Apple Freeway #2

HOLE BAF-3

Apple Freeway Design Example – Site Exploration
Exhibit D – Boring Logs (Cont'd)

REGION 3
COUNTY ORANGE
PROJECT INTERSTATE 0
DATE START 5/10/92
DATE FINISH 5/12/92
CASING O.D. 4" I.D.
SAMPLER O.D. 2" I.D. 1-3/8"
RIG TYPE Acker B-40
CORE BARREL Double Tube

SUBSURFACE EXPLORATION LOG

HAMMER FALL-CASING 18"
HAMMER FALL-SAMPLER 30"
WEIGHT OF HAMMER-CASING 300 LBS.
WEIGHT OF HAMMER-SAMPLER 140 LBS.

HOLE BAF-4
LINE Baseline
STA. 93+27
OFFSET 50' Lt.
SURF. ELEV. 991.0

TIME	4 pm	8 am	
DATE	5/10/92	5/12/92	
DEPTH TO WATER	6'	6'	

DEPTH BELOW SURFACE	BLOWS ON CASING	SAMPLE NO.	BLOWS ON SAMPLER 0/.5	.5/1.0	1.0/1.5	1.5/2.0	DESCRIPTION OF SOIL AND ROCK	MOIST CONT %
0	0	J1	1	1	1		BLACK ORGANIC SILT	120
	2						WET - PLASTIC	
	11						3'	
	25							
	31							
	40	J2	4	8	9		GR. SAND	12
	41							
	56						MOIST - NON PLASTIC	
	71							
10	83						10'	
	70	T3					(10' - 12' PUSHED TUBE 20")	33
	91							
	93							
	82		VANE				(13' VANE SHEAR TEST	
	93							
	81	T4					(15' - 17' PUSHED TUBE 20")	35
	80							
	87						GR. CLAYEY SILT	
	85		VANE				(18' VANE SHEAR TEST.	
20	90						MOIST - PLASTIC	
	82	T5					(20' - 22' PUSHED TUBE 20")	31
	86							
	87							
	85		VANE				(23' VANE SHEAR TEST	
	75							
	73	T6					(25'-27' PUSHED TUBE 20")	36
	72							
	83							
	71		VANE				(28' VANE SHEAR TEST)	
30	61							
	81	T7					(30' - 32' PUSHED TUBE 20")	38
	83							
	72							
	76							
	83							

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CONTRACTOR ______ SM ______

DRILL RIG OPERATOR Klinedinst
SOIL & ROCK DESCRIP. Chassie
REGIONAL SOILS ENGR. Cheney
SHEET 1 OF 2
STRUCTURE NAME/NO. Apple Freeway #2

HOLE BAF-4

Apple Freeway Design Example – Site Exploration
Exhibit D – Boring Logs (Cont'd)

REGION 3
COUNTY ORANGE
PROJECT INTERSTATE 0
DATE START 5/10/92
DATE FINISH 5/12/92
CASING O.D. 4" I.D.
SAMPLER O.D. 2" I.D. 1-3/8"
RIG TYPE Acker B-40
CORE BARREL Double Tube

SUBSURFACE EXPLORATION LOG

HAMMER FALL-CASING 18"
HAMMER FALL-SAMPLER 30"
WEIGHT OF HAMMER-CASING 300 LBS.
WEIGHT OF HAMMER-SAMPLER 140 LBS.

HOLE BAF-4
LINE Baseline
STA. 93+27
OFFSET 50' Lt.
SURF. ELEV. 991.0

TIME	4 pm	8 am	
DATE	5/10/92	5/12/92	
DEPTH TO WATER	5'	5'	

DEPTH BELOW SURFACE	BLOWS ON CASING	SAMPLE NO.	BLOWS ON SAMPLER 0/.5	.5/1.0	1.0/1.5	1.5/2.0	DESCRIPTION OF SOIL AND ROCK	MOIST CONT %
36	71	J8	2	2	4		GR CLAYEY SILT	38
	79						MOIST - PLASTIC	
	86	VANE					(37' VANE SHEAR TEST)	
	83							
40	85							
	82	T9					(40' - 42' PUSHED TUBE 18")	37
	81							
	93							
	91						45'	
	96							
	121	J10	7	8	15			
	450							
	391						GR SANDY GRAVEL	
	220							
50	230						MOIST - NON PLASTIC	
	200	J11	40	100				
	370							
	400							
	410						TOP OF ROCK — 55'	
	380							
							HARD UNWEATHERED BASALT	
							Run 1 - 55' - 60' (60") RECOVERY 58", 21 PIECES ROD 90%	
							60'	
60								
							Run 2 - 60' - 65' (60") RECOVERY - 60", 5 PIECES ROD 95%	
							HARD UNWEATHERED BASALT	
							end of boring 65'	
70								

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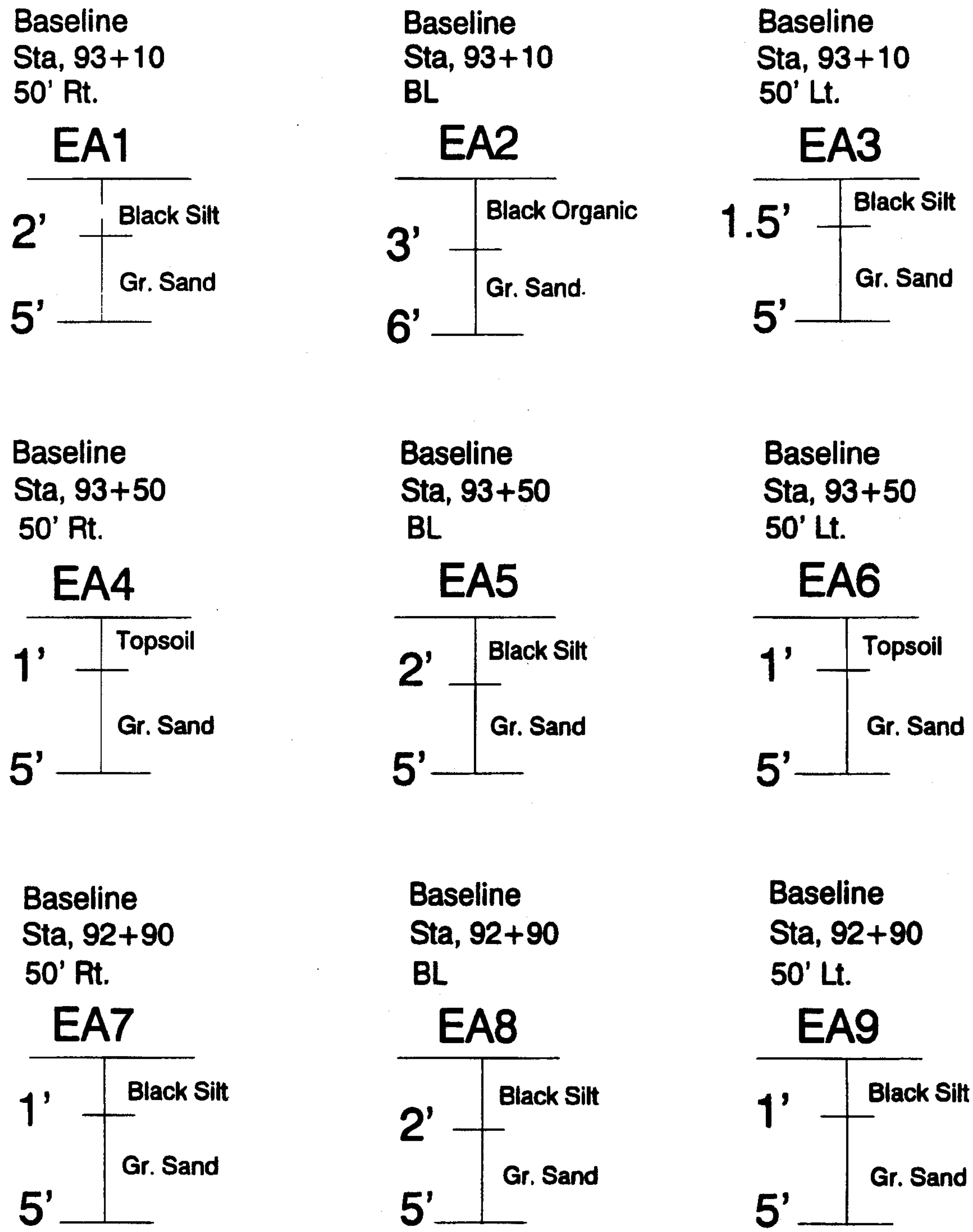
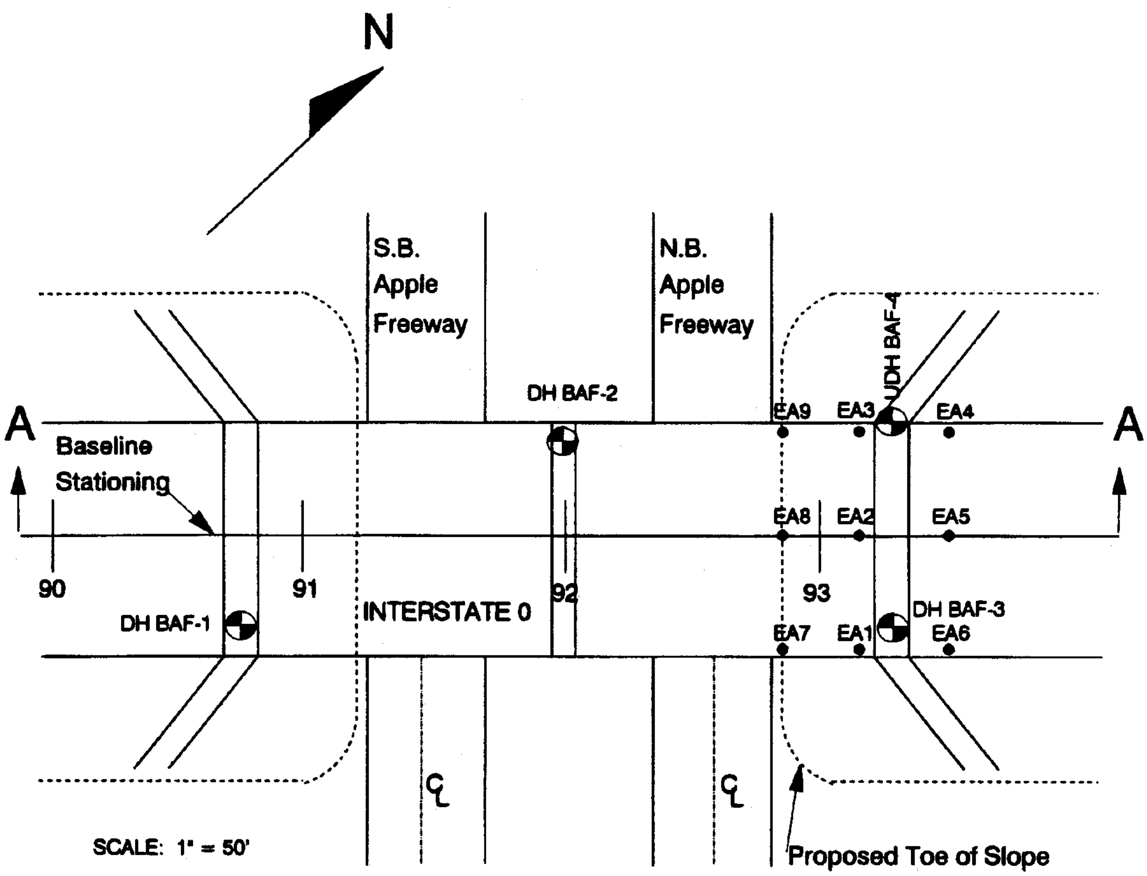
CONTRACTOR ____________ SM ____________

DRILL RIG OPERATOR Klinedinst
SOIL & ROCK DESCRIP. Chassie
REGIONAL SOILS ENGR. Cheney
SHEET 2 OF 2
STRUCTURE NAME/NO. Apple Freeway #2
HOLE BAF-4

Apple Freeway Design Example – Site Exploration
Exhibit D - Boring Logs (Cont'd)



Apple Freeway Design Example – Site Exploration
Exhibit E – East Abutment Area Hand Auger Hole Logs



Apple Freeway Design Example – Site Exploration
Exhibit F – Final Exploration Locations

Summary of the Site Exploration Phase for Apple Freeway Design Problem

- Terrain Reconnaissance

  Delta landform - possible clay deposit buried

- Site Inspection

  Unsuitable soils near east approach embankment

- Subsurface Borings

  Hand auger holes define limits and depth of unsuitable organic deposit.

  SPT drill holes show sand over clay over gravel and rock.

  Undisturbed samples and vane shear tests taken in clay.